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Radiographic comparison of weight-bearing and non-weight-bearing positions in evaluating the distal tibiofibular syndesmosis: a single-center study of 72 ankles

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Abstract

Introduction The distal tibiofibular syndesmosis is a key structure for the ankle joint's stability and function, especially when the body is weight-bearing. Recent literature indicates that weight-bearing radiographs demonstrate superior diagnostic yield compared to non-weight-bearing radiographs. This study aimed to determine the diagnostic yield of the weight-bearing compared to the non-weight-bearing radiographs.

Materials and Methods A total of thirty-six healthy adult individuals, with an age group ranging from 18 to 65 years, who had never experienced any trauma, were selected for this study. We performed radiographic imaging in three planes of view: anterior-posterior, lateral, and mortise, for both ankles under both weight-bearing and non-weight-bearing conditions. The tibiofibular clear space, tibiofibular overlap, medial clear space, tibiofibular distance-lateral, anteroposterior tibiofibular ratio, and Lateral Tibial (LT) width were measured.

Results Tibiofibular clear space and anteroposterior tibiofibular ratio were higher in the weight-bearing position, while tibiofibular overlap, medial clear space, and lateral tibiofibular distance were higher in the non-weight-bearing position. There was a gender effect, as males had higher values for most of the parameters; however, no significant difference was seen in the anteroposterior tibiofibular ratio and tibiofibular distance lateral. The results of this study demonstrate that X-rays of the distal tibiofibular syndesmosis reveal very different outcomes when the person is bearing weight or not pulling weight. These clinically significant differences suggest that weight-bearing radiographs may enhance the identification and diagnosis of syndesmotic injuries. Further studies will be necessary to help with the refinement of the imaging protocols and to improve diagnostic accuracy based on various types of patient demographics.

Conclusion WB radiographs provide a more functionally accurate assessment of syndesmotic integrity than NWB imaging. They should be incorporated into routine diagnostic protocols, especially for active individuals and those

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with higher BMI. These findings support the need for demographic-specific imaging strategies to improve diagnostic precision.

Keywords Tibiofibular syndesmosis, Tibiofibular clear space, Tibiofibular overlap, Syndesmotic injuries, Anteroposterior tibiofibular ratio

Introduction

The distal tibiofibular syndesmosis plays a critical role in maintaining the stability and function of the ankle joint during weight-bearing (WB) activities. Its unique ligamentous structure allows for restricted motion between the tibia and fibula, facilitating efficient load distribution across the ankle joint. However, injuries to this structure, such as syndesmotic sprains or diastasis, can lead to instability, chronic pain, and long-term functional impairment if not accurately diagnosed and managed [1, 2].

Diagnosing syndesmotic injuries heavily relies on imaging techniques, including conventional radiography, MRI, CT scans, and ultrasonography. While MRI and CT scans offer high specificity and detailed visualization, their widespread use is often constrained by factors such as cost, availability, and patient contraindications. CT scans, for instance, involve ionizing radiation exposure, posing risks to biological tissues [3]. Ultrasonography, though less specific than MRI, may serve as an alternative in certain cases [4, 5]. Non-weight-bearing (NWB) X-rays are still commonly used in clinical practice. However, new research suggests that weight-bearing (WB) imaging gives better information about how well the syndesmosis works when it is under physiological loads [1, 6]. WB radiographs are particularly effective in detecting subtle instabilities and syndesmotic diastasis, which may not be apparent on NWB images, especially during the acute phase or post-operative evaluation [6].

Despite the growing application of WB radiographs, there remains a critical need for further research directly comparing WB and NWB imaging techniques in assessing syndesmotic injuries. Existing studies have yielded inconsistent findings, with some demonstrating significant differences between the two modalities, while others report minimal variations [7].

This study aimed to address these gaps by evaluating the effects of WB and NWB radiological examinations on the distal tibiofibular syndesmosis in a sample of 72 ankles. Using key radiological parameters such as tibiofibular clear space (TFCS), tibiofibular overlap (TFO), and medial clear space (MCS), the study seeks to determine whether WB imaging provides clinically significant insights into syndesmotic integrity. Additionally, it explores the influence of demographic factors, including gender and body mass index (BMI), on syndesmotic anatomy and function, addressing a notable gap in the existing literature. Thus, the results of this investigation would provide necessary information for the development and optimization of diagnostic approaches regarding injuries of syndesmotic anatomical functions and for choosing techniques of imaging depending on various patient demographics.

Materials and methods

The study was conducted on 36 healthy adult volunteers without a history of trauma within the age bracket of 18–65 years at the Başkent University Konya Research Center. Volunteers were excluded if they had a history of pregnancy, neuropathic disease, prior fracture or ligamentous injury, previous ankle surgery, or any bone pathology such as a tumor.

We noted the age, sex, weight, and height of all participants.

To allow functional grading, all patients had standard X-rays taken of both ankles, one on each side, in three different positions, with and without weight bearing (Fig. 1).

Radiographic technique

All X-rays were acquired by trained radiology technicians under standardized conditions to minimize bias and ensure reliability.

Ankle AP-WB view

Each patient stood upright, with their ankles centered and perpendicular to the detector, their toes pointing toward the X-ray tube, and their feet in a neutral rotation. We distributed the weight evenly and provided each patient with something to hold onto to maintain balance. The midpoint of the lateral and medial malleoli serves as the centering point for this view [8] (Fig. 1a).

Ankle mortise: WB view

Each patient stood on an upright bench with the ankle perpendicular to the detector. The leg was rotated 20° internally. The midpoint of the lateral and medial malleoli serves as the centering point for this view [9] (Fig. 1b).

Ankle AP-NWB view

Each patient sat upright with their legs straight on the table. The foot was in a neutral position. Toes pointed directly toward the ceiling. The midpoint of the lateral and medial malleoli serves as the centering point for this view [10] (Fig. 1c).

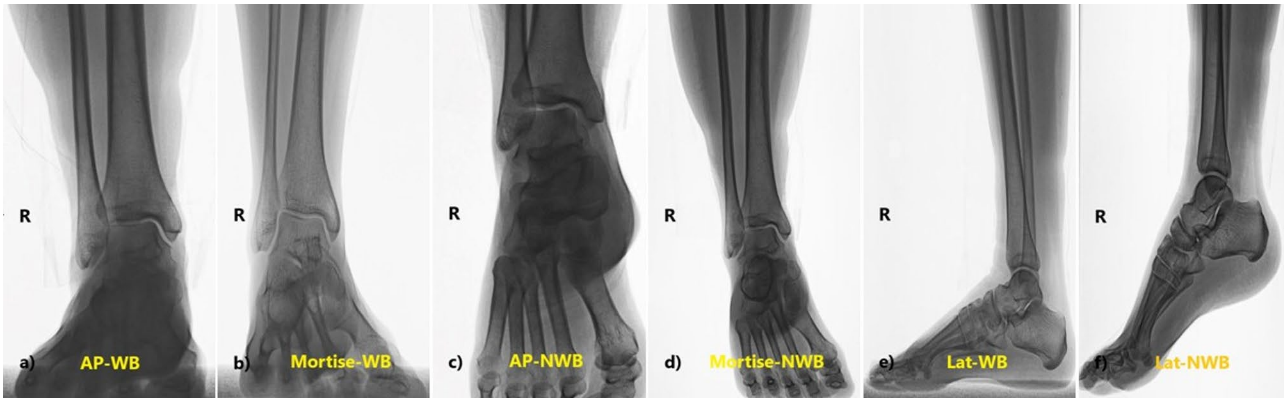

Fig. 1 Radiographic views of the right ankle in various positions: 1a- Anteroposterior weight-bearing view, 1b- Mortise weight-bearing view, 1c- Anteroposterior non-weight-bearing view, 1d- Mortise non-weight-bearing view, 1e- Lateral weight-bearing view, 1f- Lateral non-weight-bearing view

Ankle mortise-NWB view

Each patient sat upright with their legs straight on the table. The leg was rotated 20° internally. The midpoint of the lateral and medial malleoli serves as the centering point for this view [11] (Fig. 1d).

Ankle lateral-WB view

Each patient stood on an upright stand with their ankle parallel to the detector. We distributed their weight evenly and provided them with a hold to maintain their balance [12] (Fig. 1e).

Ankle lateral-NWB view

We placed each patient on the table in a lateral position. The lateral aspect of the knee and ankle joints was in contact with the table. The tibia was positioned parallel to the table. The individual flexed his leg. The foot was in a normal position. To prevent excessive rotation, the contralateral leg was positioned posteriorly [13] (Fig. 1f).

For all AP positions, the collimator was collimated from laterally to the skin margins, superior to examine the distal third of the tibia and fibula, and inferior to the proximal aspect of the metatarsals, and for all lateral positions, The collimator was collimated from the posterior part of the foot to the skin edges of the most posterior part of the calcaneus at the front, to examine the distal third of the tibia and fibula at the top, and to the skin edges of the plantar aspect of the foot at the bottom.

The X-ray beam settings were as follows: 10 mAs, 60 kV, detector size 24 cm x 30 cm, and a focus distance of 100 cm for all views.

The ankle syndesmosis parameters were measured separately by two orthopedic specialists who did not know how the other specialist scored. For each parameter, the average of the differences between the measurements made by the two specialists was then found. All X-ray images were reviewed, and digital measurements were conducted using ClearCanvas. Workstation version 1.0.0.0 (Source) system.

Following confirmation of appropriate radiographic technique, the following were measured on both AP and mortise views: TFCS, TFO, MCS, and the width of the tibia and fibula, as well as the distance from the incisura fibularis to the lateral edge of the tibia (Lateral Tibial -LT width) (Fig. 2).

The measurement landmarks are as follows,

TFCS-AP tibiofibular clear space- anteroposterior view
TFCS-M tibiofibular clear space- mortise view

The tibiofibular clear space can be measured on an AP or mortice view of the ankle. It is measured 1 cm above the tibial plafond. It is described as the horizontal distance between the deepest point of the fibular groove or posterior tibial tubercle and the medial edge of the distal fibula. (The normal range for these indices is less than 6 mm) [14].

TFO-AP tibiofibular overlap- anteroposterior view
TFO-M tibiofibular overlap- mortise view

This measurement can be made on AP or mortise projections. The horizontal distance between the lateral margin of the anterior tubercle and the medial contour of the fibula is measured parallel and about 1 cm above the distal tibial plafond in a normal anteroposterior view of the ankle [15]. (The normal range for TFO-AP is greater than 6 mm, and the normal range for TFO-M is greater than 1 mm.) [16].

MCS-AP medial clear space- anteroposterior view
MCS-M medial clear space- mortise view

The medial clear space can be measured on the non-stressed and stressed ankle mortise views, as the widest distance between the lateral border of the medial malleolus and the medial side of the talus, and is usually measured parallel to the superior talar articular surface. This

Fig. 2 Normal radiographic landmarks seen on an Anteroposterior weight-bearing view: TFCS (Tibiofibular Clear Space), TFO (Tibiofibular Overlap), MCS (Medial Clear Space), LT width (from the incisura fibularis to the lateral tibia border)

can be measured at the level of the talar dome (common) or 5 mm inferior to the talar dome. (A medial clear space of ≥ 4–5 mm has been considered abnormal) [17].

APTF ratio anteroposterior tibiofibular ratio

anterior cortex of the tibia at the level of the physeal scar (a), intersection of the anterior cortex of the fibula and the tibial physeal scar (b), Anteroposterior tibiofibular (APTF) ratio = a/b (mean is typically 0.94) [18].

TFD-LAT tibiofibular distance- lateral view

distance from the posterior cortex of the fibula to the posterior cortex of the tibia on the lateral view [16].

LT-AP lateral tibia- anteroposterior view

LT-M lateral tibia- mortise view

The width of the tibia and fibula and from the incisura fibularis [19].

Assessment of fibular translation was performed by measuring the Anteroposterior tibiofibular (APTF) ratio and Distal Posterior Tibiofibular distance (TFD-LAT) on lateral radiographs to evaluate the position of the fibula in terms of lateral translation, posterior translation, and external rotation (Figs. 3 and 4).

The current study, therefore, sought to use the results from these 72 cases examined to establish norms for TFCS, TFO, MCS, and lateral tibia and fibula widths in

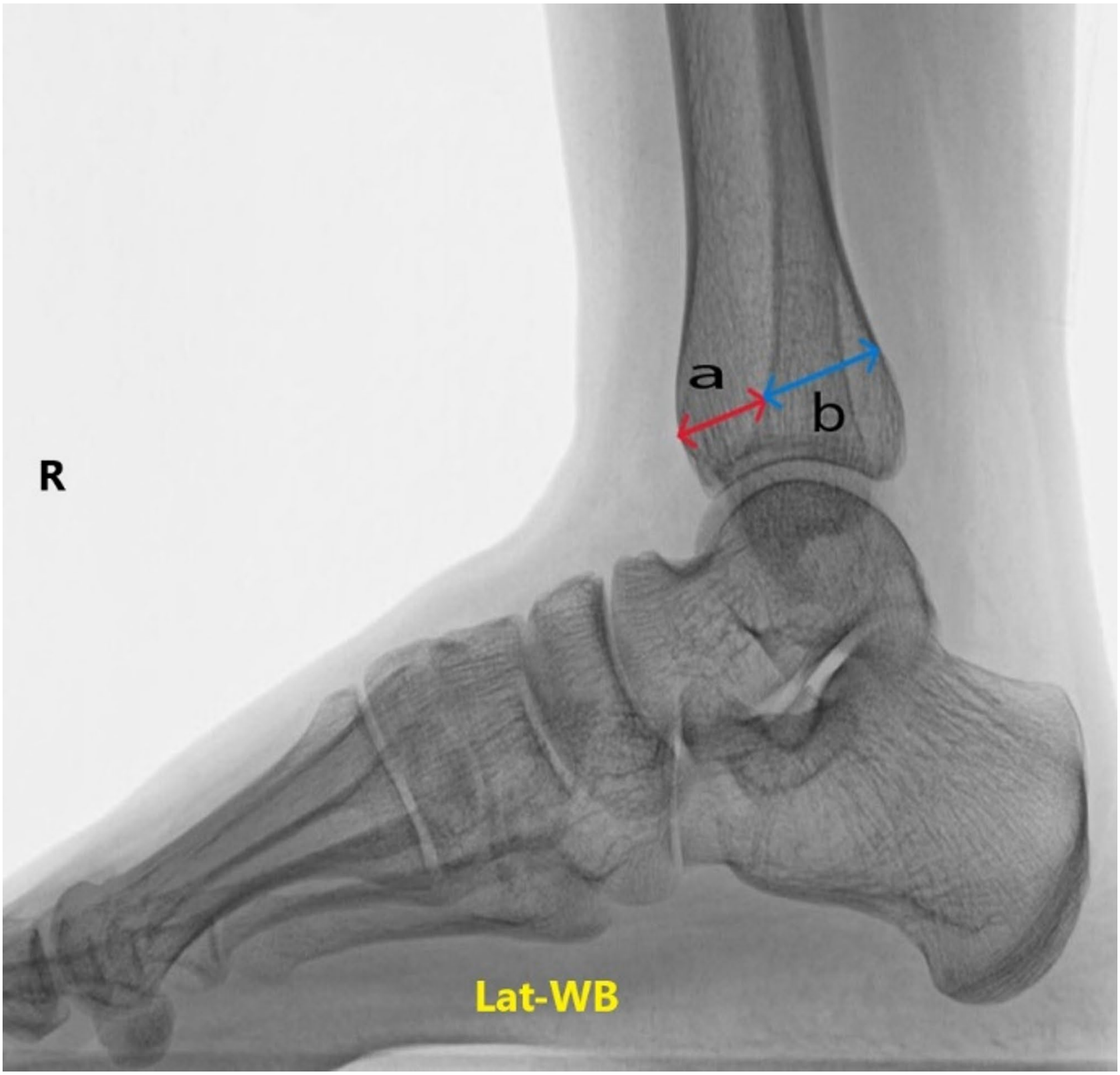

Fig. 3 Normal radiographic landmarks seen on a lateral weight-bearing view: 3a- anterior cortex of the tibia at the level of the physeal scar, 3b- intersection of the anterior cortex of the fibula and the tibial physeal scar, Anteroposterior tibiofibular (APTF) ratio = a/b

our setting and compare the same with available data from the global community.

Statistical analysis: SPSS 26.0 was utilized for data processing. The distribution of continuous variables was tested graphically (Q-Q Plot) and by the normality test ''Shapiro-Wilk''. The assumption of ''Normal Distribution'' was met for all variables. Comparisons of repeated measurements were performed using the ''Paired Samples t test'' and comparisons of independent groups by means of ''Independent Samples t test''. Continuous variables relations were analyzed by the Pearson Correlation method. Type 1 error margin in all statistical comparison tests was α:0.05 and tested as two-tailed.

Results

A total of 36 healthy volunteers, 15 (42%) Male and 21 (58%) Female, were included in the study. The mean age was 33.52 (± 8.78), the median value was 33.5 years, the youngest was 21, and the oldest was 53 years old. The mean BMI was 23.31 (± 3.81).

In the subjects, 72 ankles, both right and left, were matched for radiological measurement parameters taken in WB and NWB, and t test analysis was performed in

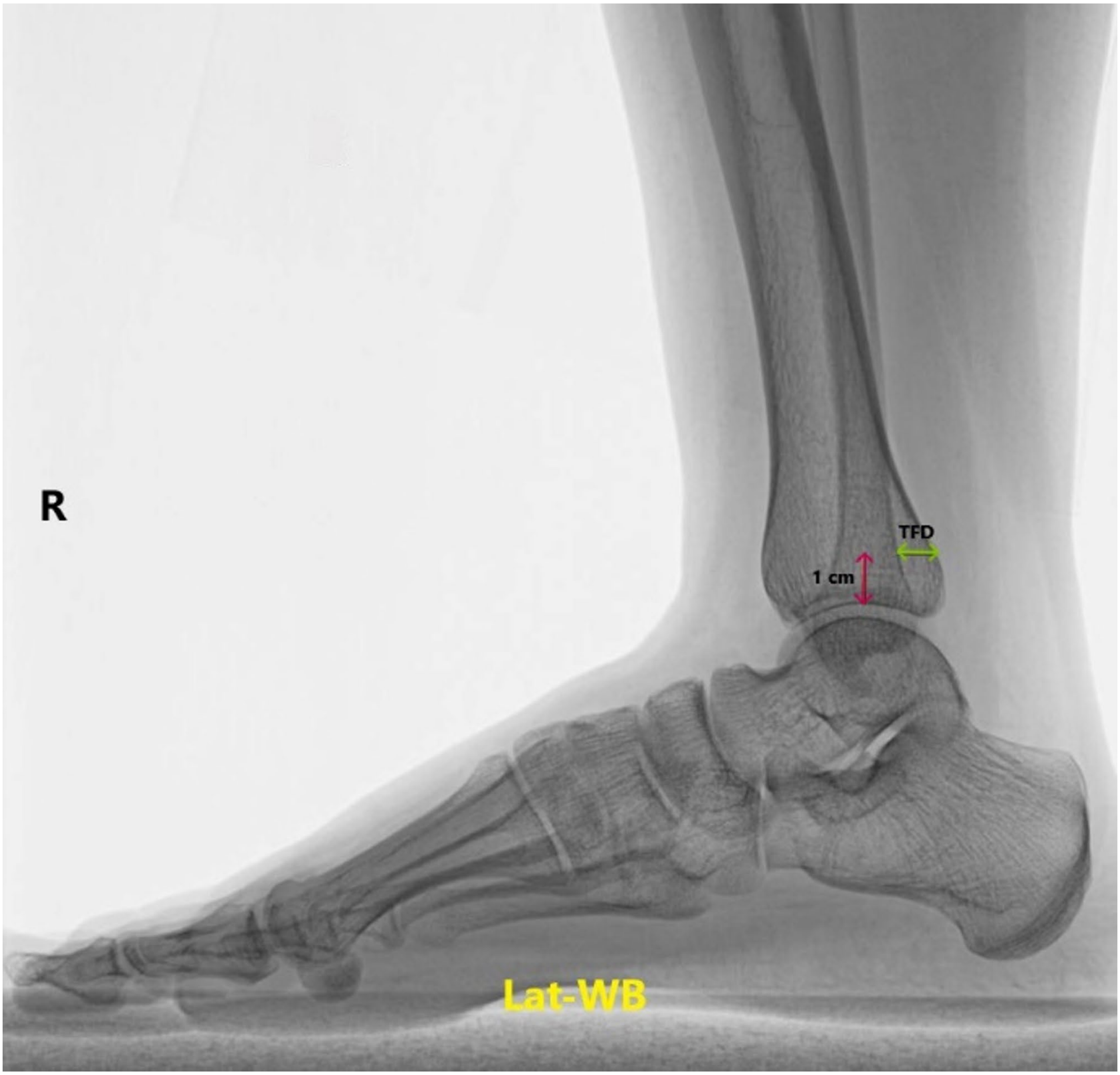

Fig. 4 TFD-LAT, distance from the posterior cortex of the fibula to the posterior cortex of the tibia on the lateral view

repeated measurements; statistically significant differences were found in all of these parameters (Table 1). TFCS and APTF ratio values were significantly higher in the WB position, whereas TFO, MCS, LT, and TFD-LAT measurements predominated in the NWB position. The research hypothesis that radiological measurements taken in WB and NWB positions would not differ was rejected.

The relationship between the WB and NWB difference value (Diff.) of the radiological measurement results of the ankle and age and BMI as a result of the Pearson correlation analysis; a negative correlation was found between age and TFD-LAT (Diff.) and a positive low-level correlation was found between BMI and TFO-AP (Diff.) (Table 2). While the majority of radiological parameters did not show statistically significant correlations with age or BMI, two parameters did: a positive low-level correlation was observed between BMI and TFO-AP (Diff.), and a negative correlation was found between age and TFD-LAT (Diff.) based on Pearson correlation analysis. Therefore, the hypothesis that WB–NWB differences are unrelated to age and BMI was not entirely rejected but rather rejected only for the remaining parameters.

Ankle WB, NWB radiological measurement parameters, and Diff. (WB-NWB) Values were examined with an independent-sample t test for the difference between

Table 1 Comparison of WB and NWB radiological measurements

	(WB) Mean ± SD	(NWB) Mean ± SD	Mean Diff. Mean (95%CI)	*p**	Effect Size** Cohen's d Value
TFCS-AP	44.1 ± 8.7	42.1 ± 9.4	1.98 (0.08; 3.88)	0.041	0.24
TFCS-M	43.9 ± 7.2	41.8 ± 7.9	2.12 (0.49; 3.75)	0.012	0.30
TFO-AP	67.1 ± 25.2	78.7 ± 23.6	-11.6 (-15.80; -7.41)	< 0.001	0.65
TFO-M	27.3 ± 15.5	49 ± 21.4	-21.67 (-25.27; -18.06)	< 0.001	1.41
MCS-AP	29.1 ± 3.7	32.1 ± 4.2	-3.03 (-4.12; -1.94)	< 0.001	0.65
MCS-M	24.8 ± 4.3	28.8 ± 4.8	-3.92 (-4.89; -2.95)	< 0.001	0.95
LT-AP	109.3 ± 22.4	122 ± 22.6	-12.79 (-16.07; -9.51)	< 0.001	0.92
LT-M	72.4 ± 16.4	90.7 ± 22.8	-18.22 (-22.37; -14.08)	< 0.001	1.03
APTF Ratio	1.37 ± 0.28	0.96 ± 0.25	0.42 (0.35; 0.48)	< 0.001	1.43
TFD-LAT	35.9 ± 18.9	62 ± 27	-26.1 (-31.00; -21.20)	< 0.001	1.25

* Paired Samples t test. ** Cohen's d value (< 0.1 No Effect, 0.1–0.4 Small Effect, 0.4–0.7 Intermediate Effect,>0.7 Large Effect)

Table 2 The relationship between diff. (WB-NWB) age and BMI

Diff. (WB-NWB)	Age		BMI	
	r	*p*	*r*	*p*
TFCS-AP	-0.004	0.971	-0.008	0.945
TFCS -M	-0.118	0.324	+ 0.008	0.946
TFO-AP	-0.011	0.927	**+ 0.246***	0.038
TFO-M	-0.161	0.176	+ 0.026	0.830
MCS-AP	-0.113	0.345	-0.081	0.498
MCS-M	+ 0.168	0.159	+ 0.199	0.094
LT-AP	-0.055	0.648	+ 0.183	0.124
LT-M	-0.189	0.111	+ 0.022	0.857
APTF Ratio	+ 0.125	0.294	+ 0.020	0.864
TFD-LAT	**-0.237***	0.045	+ 0.004	0.975

*Correlation is significant at 0.05

genders; There was no significant difference between genders in TFCS-AP measurements. TFCS-M measurements were found to be higher in men for WB position, the difference was statistically significant, and there was no statistically significant difference for NWB and Diff. (WB-NWB). TFO-AP was found to be higher in men than in women in all measurements. TFO-M WB and NWB were found to be statistically significantly higher in men, while Diff. (WB-NWB) was not significantly different between men and women. There was a statistically significant difference in all MCS-AP measurements in men, they were found to be higher in men. MCS-M WB and NWB were statistically significantly higher in men, there was no Diff. (WB-NWB). LT-AP, both WB, NWB, and Diff. (WB-NWB) were found to be significantly higher in males. LT-M measurements were found to be statistically significantly higher in WB and NWB males, while Diff. (WB-NWB) was found to be similar. No significant difference was found between genders for APTF Ratio and TFD-LAT (Table 3).

Discussion

The results of this study illustrate significant radiographic differences between WB and NWB states when evaluating distal tibiofibular syndesmosis and thus confirm the role of WB radiography in the functional analysis of syndesmotic stability. Given the diagnostic challenges posed by the subtle radiographic presentation of syndesmotic injuries, our findings underscore the diagnostic potential of WB imaging on multiple parameters, most notably for TFCS, TFO, and MCS. These findings align with emerging literature and further support the use of WB imaging in diagnostic protocols.

The significant rise of TFCS under WB conditions in both AP and mortise views (TFCS-AP and TFCS-M, $p = 0.041$ and $p = 0.012$) supports the dynamic widening effect under physiological loading. This kind of widening effect was well-documented in previous studies where the syndesmotic space is recorded to widen under WB due to an external rotational pull on both tibia and fibula [20].

Importantly, Del Buono et al. (2013) emphasized that 'syndesmotic injuries, if not diagnosed promptly and managed appropriately, can lead to chronic instability, osteoarthritis, and long-term functional disability,' underscoring the clinical imperative for accurate imaging modalities like WB radiography to guide early intervention [21].

Phisitkul et al. reiterated that WB imaging is closer to functional joint loading, which tends to reveal

Table 3 Gender comparisons of WB, NWB, and diff. (WB-NWB)

	Male	Female	Mean Diff.	p	Effect Size**
	Mean ± SD	Mean ± SD	Mean (95%CI)		Cohen's d Value
TFCS-AP (WB)	44.1 ± 9.4	44.1 ± 8.3	0.01 (-4.16; 4.18)	0.997	0.00
TFCS -AP (NWB)	41.6 ± 11.3	42.5 ± 8	-0.89 (-5.70; 3.93)	0.713	0.09
TFCS-AP (WB-NWB)	2.5 ± 9.2	1.6 ± 7.2	0.89 (-2.97; 4.76)	0.646	0.11
TFCS-M (WB)	46.1 ± 6	42.4 ± 7.6	3.76 (0.44; 7.09)	0.027	0.54
TFCS -M (NWB)	43.3 ± 7.8	40.8 ± 8	2.48 (-1.28; 6.25)	0.193	0.31
TFCS -M (WB-NWB)	2.9 ± 6.6	1.6 ± 7.2	1.32 (-2.01; 4.65)	0.431	0.19
TFO-AP (WB)	87 ± 21.1	52.9 ± 16.9	34.15 (25.22; 43.08)	< 0.001	1.82
TFO-AP (NWB)	91.6 ± 24.5	69.5 ± 18.4	22.05 (11.99; 32.12)	< 0.001	1.05
TFO-AP (WB-NWB)	-4.6 ± 19.5	-16.6 ± 14.8	12.09 (4.03; 20.16)	< 0.001	0.71
TFO-M (WB)	32.9 ± 16.4	23.3 ± 13.7	9.55 (2.46; 16.64)	0.009	0.64
TFO-M (NWB)	56.6 ± 23.6	43.5 ± 18.1	13.09 (2.79; 23.39)	0.014	0.64
TFO-M (WB-NWB)	-23.7 ± 16.3	-20.2 ± 14.6	-3.54 (-10.85; 3.77)	0.337	0.23
MCS-AP (WB)	31.7 ± 3.4	27.2 ± 2.7	4.53 (3.10; 5.96)	< 0.001	1.51
MCS-AP (NWB)	33.4 ± 3.7	31.2 ± 4.4	2.20 (0.23; 4.16)	0.029	0.53
MCS-AP (WB-NWB)	-1.7 ± 3.8	-4 ± 4.9	2.33 (0.18; 4.49)	0.034	0.52
MCS-M (WB)	27.1 ± 3.7	23.2 ± 3.9	3.94 (2.11; 5.77)	< 0.001	1.03
MCS-M (NWB)	30.8 ± 5.1	27.3 ± 4.1	3.46 (1.28; 5.63)	0.002	0.76
MCS-M (WB-NWB)	-3.6 ± 4.7	-4.1 ± 3.7	0.49 (-1.49; 2.47)	0.626	0.12
LT-AP (WB)	126.4 ± 20	97 ± 14.6	29.46 (20.85; 38.07)	< 0.001	1.73
LT-AP (NWB)	135.1 ± 23.1	112.8 ± 17.1	22.30 (12.30; 32.30)	< 0.001	1.12
LT-AP (WB-NWB)	-8.6 ± 12	-15.8 ± 14.6	7.16 (0.68; 13.64)	0.031	0.53
LT-M (WB)	79.7 ± 16.1	67.2 ± 14.6	12.52 (5.2; 19.78)	0.001	0.82
LT-M (NWB)	100.5 ± 25.4	83.6 ± 18	16.91 (6.05; 27.77)	0.003	0.79
LT-M (WB-NWB)	-20.8 ± 20.3	-16.4 ± 15.5	-4.39 (-12.80; 4.02)	0.301	0.25
APTF Ratio (WB)	1.44 ± 0.25	1.33 ± 0.29	0.11 (-0.02; 0.25)	0.089	0.41
APTF Ratio (NWB)	0.99 ± 0.27	0.94 ± 0.24	0.06 (-0.06; 0.18)	0.361	0.22
APTF Ratio (WB-NWB)	0.45 ± 0.25	0.39 ± 0.31	0.06 (-0.08; 0.20)	0.400	0.20
TFD-LAT(WB)	37.9 ± 17.8	34.5 ± 19.8	3.36 (-5.68; 12.40)	0.461	0.18
TFD-LAT(NWB)	64.5 ± 29	60.3 ± 25.7	4.25 (-8.68; 17.18)	0.514	0.16
TFD-LAT(WB-NWB)	-26.6 ± 21.9	-25.7 ± 20.3	-0.89 (-10.90; 9.12)	0.860	0.04

*Independent-sample t test. ** Cohen's d value (< 0.1 No Effect. 0.1–0.4 Small Effect. 0.4–0.7 Intermediate Effect. >0.7 Large Effect)

instabilities not often detected by NWB imaging. Equally important, the study by Zalavras et al. and Egol et al. confirms that TFCS measurements under WB provide a suitable representation of syndesmotic integrity. This is particularly relevant in the diagnosis of athletes or other active individuals who are susceptible to syndesmotic injury and thus require evaluation under functional load. Gravity stress radiographs appear to increase the need for operative treatment [22–25].

On the other hand, some authors have suggested that NWB imaging may overestimate TFCS widening in the absence of loading forces, thus leading to overtreatment. They include Gardner et al. and Bekerom et al. [26, 27]. Therefore, these studies confirm the importance of WB imaging for properly diagnosing syndesmotic injuries, which avoids misunderstanding of TFCS widening in NWB images.

The findings of this study are consistent with those reported by Pneumaticos et al., who emphasized the significant impact of rotational dynamics on the radiographic evaluation of tibiofibular syndesmosis [28]. Their research demonstrated that variations in foot positioning could substantially alter radiological measurements, highlighting the necessity for standardized imaging techniques to ensure accuracy. In alignment with their conclusions, our study also observed notable differences in TFCS and TFO values between WB and NWB conditions, reinforcing the importance of physiological loading during imaging to assess syndesmotic integrity.

The evaluation of tibiofibular syndesmosis injuries is commonly performed through radiographic imaging, with weight-bearing and non-weight-bearing X-rays being pivotal in diagnosing instability. As highlighted by Magan et al. (2014),[u1] while advanced imaging techniques like CT and MRI provide detailed information, conventional X-rays in weight-bearing positions can effectively assess syndesmotic involvement and guide management. Our study, comparing weight-bearing and non-weight-bearing radiographs, supports the notion that weight-bearing views offer valuable insights into syndesmotic injury severity, aligning with current clinical practices for diagnosing and managing such injuries [29].

Additionally, Lepojärvi et al. utilized weight-bearing computed tomography (WBCT) to examine the rotational dynamics of the distal tibiofibular joint, revealing that WB imaging is more effective in identifying subtle instabilities that might not be evident in NWB conditions [30]. These findings align with our study, which demonstrated the superior diagnostic utility of WB imaging, particularly for parameters such as TFCS-AP, TFCS-M, and the APTF ratio. This underscores the clinical relevance of WB imaging, especially for evaluating joint functionality in active populations.

These results collectively contribute to the growing body of evidence supporting the diagnostic advantages of WB imaging over NWB imaging for syndesmotic injuries. Our study builds on this foundation by employing standardized radiographic techniques and offering normative data for the syndesmosis under physiological load conditions, which may enhance diagnostic precision and clinical decision-making.

A recent Level I evidence-based meta-analysis further corroborates the clinical relevance of syndesmotic stability assessment, demonstrating that suture button fixation achieves significantly better functional outcomes compared to screw fixation in talofibular syndesmotic injuries (Migliorini et al., 2024). This underscores the critical role of accurate diagnostic modalities like WB radiography in guiding optimal treatment selection [31].

TFO measurements also displayed significant WB versus NWB differences, with WB values notably lower than NWB ($p<0.001$ for TFO-AP and TFO-M), suggesting that loading forces reduce overlap by drawing the fibula closer to the tibia. This phenomenon has been reported by Seidel et al. and Beumer et al., who noted that the compressive effects of WB facilitate a more stable joint configuration by minimizing overlap [25, 32]. Our study's effect sizes for TFO were large (Cohen's d = 0.65 and 1.41), further underscoring the clinical relevance of this difference. LaMothe et al. previously discussed the clinical implications of these WB-induced changes, recommending WB imaging to avoid misdiagnosing syndesmotic instability in cases where NWB TFO measurements could exaggerate apparent displacement [33].

Moreover, Hunt et al. found that TFO's sensitivity to WB conditions is paramount in the high-demand settings of athletic populations, as WB imaging reflects functional joint stability [34]. Perelli et al. confirmed similar results, finding TFO values critical for accurate assessment in syndesmotic injuries and concluding that NWB imaging often inadequately represents TFO dynamics, particularly in active individuals [35].

MCS was also significantly lower under WB, in agreement with the studies of Zalavras et al., who determined WB imaging to be an important modality in the appropriate reproduction of syndesmotic stability [23]. An increased MCS in NWB radiographs can also result in false positives for the diagnosis of syndesmotic injuries because NWB imaging does not have functional loading to capture true syndesmotic integrity. However, our MCS study results, $p<0.001$, support those of Porter et al., who advised WB imaging for the reliable assessment of MCS because it is less prone to overestimation with regard to medial widening [36].

The significant increase in LT-AP and LT-M under NWB conditions aligns with Zalavras et al., who found that NWB conditions might artificially exaggerate syndesmotic displacement [24]. A study done by Seidel et al. highlighted that WB compression stabilizes the joint, reducing false indications of instability [25, 37]. Our findings align with Gardner et al. and van den Bekerom et al., whose work supports the utility of LT measurements under WB, revealing that NWB measurements risk overestimating instability due to the lack of stabilizing load forces [26, 27].

The Tibiofibular Distance (TFD-LAT), as measured via lateral radiographs in this study, demonstrated significant differences between WB and NWB conditions. NWB conditions exhibited higher TFD-LAT values, reflecting a greater posterior translation and external rotation of the fibula relative to the tibia in the absence of physiological loading forces. These findings align with Beumer et al., who highlighted that NWB imaging could overestimate posterior translation due to the lack of stabilizing compressive forces under load-bearing conditions [32].

Both Zalavras et al. and Gardner et al. It was determined that weight-bearing conditions compress the tibiofibular joint. This compression makes it appear to move less, thereby providing a more accurate representation of functional stability [23, 26]. This supports the idea that TFD-LAT values measured in WB conditions are a better indicator of syndesmotic integrity and are less likely to overestimate instability than NWB imaging.

Additionally, this study identified a negative correlation between age and TFD-LAT differences, suggesting that joint flexibility decreases with age. This finding agrees with what Zalavras et al. found, which is that older people's less flexible ligaments may change how syndesmotic dynamics work when they are loaded. These results suggest that diagnostic thresholds based on age may help in understanding TFD-LAT differences in clinical practice [23].

A strong negative relationship ($p<0.05$) between age and TFD-LAT differences suggests that joint flexibility decreases with age. This is supported by the work of Zalavras et al. and LaMothe et al., who found that older patients had less joint elasticity and ligamentous flexibility [23, 33]. This link is important for doctors because it means that younger patients may have more syndesmotic widening when they are bearing weight than older patients.

Similarly, a positive correlation between BMI and TFO-AP indicates that heavier patients may experience increased overlap under WB. This fits with what Gardner et al. found, which is that BMI has a big effect on syndesmotic stability when the body is bearing weight [26].

Significant gender differences were found in the present study, especially in the cases of TFO and MCS in both the WB and NWB conditions. These findings agree with Perelli et al., who found higher values for syndesmotic measurements in males due to differences in ligamentous laxity and anatomy [35]. Talia et al.'s results showed that there is a lack of scientific reporting of gender differences of foot and ankle injuries, and so, they adjusted the diagnosis threshold value according to gender in the measurements of the syndesmosis [36, 37].

The observation regarding the absence of gender-related differences in WB versus NWB-TFCS measurements aligns with findings in studies that explore syndesmotic measurements. For example, research analyzing syndesmotic parameters using weight-bearing AP radiographs found no significant gender differences in TFCS values, suggesting that this measurement is less sensitive to gender variability. In contrast, other parameters, such as TFO, did show significant gender-related differences [27]. However, the values of TFO were higher for males; this might suggest that these increases could possibly be attributed to factors of anatomy. Similarly reported that cadaveric studies may also present TFO due to differences in bone morphology between genders [32].

Regarding foot positioning in the non-weight-bearing (NWB) state, it may be assumed that variations could influence radiologic parameters used to assess syndesmotic integrity in the subjects enrolled in this study. However, Souleiman et al. investigated the impact of foot positioning on radiographic measurements relevant to diagnosing syndesmotic injuries. Their findings indicated that external rotation of the foot under load is the most sensitive position for detecting isolated or subtle syndesmotic instability [38, 39].

In contrast, a review of the literature examining the effects of plantar flexion in NWB radiographic views reported no significant changes in commonly used diagnostic parameters, such as the medial clear space and tibiofibular clear space, suggesting that these measurements remain reliable despite foot positioning in NWB conditions.

Future advancements in deep learning and artificial intelligence are anticipated to revolutionize diagnostic and prognostic accuracy [40].

Weight-bearing (WB) imaging demonstrates a functionally precise evaluation of syndesmotic integrity. Several studies have affirmed its diagnostic importance in this context [23, 41].

Conclusion

This study highlights the superior diagnostic value of weight-bearing (WB) radiographs in assessing distal tibiofibular syndesmosis, with significant differences noted in key radiological parameters compared to non-weight-bearing (NWB) imaging. WB imaging more accurately reflects functional joint stability.

Considering the impact of demographic factors, including gender, weight-bearing radiographs should be regarded as an essential element in the assessment of suspected syndesmotic injuries. Additional multicenter studies are necessary to enhance diagnostic criteria and develop patient-specific protocols.

Limitations

However, this study is limited by its single-center design and relatively small sample size. Future multicenter studies with larger and more diverse populations are necessary to validate these findings. Further research is also needed to refine WB imaging protocols based on demographic variables such as age, sex, and BMI, to enhance diagnostic accuracy across all patient groups.

"It is accurate that the BMI distribution in our sample did not include obese individuals, as demonstrated by the mean BMI of 23.31 (SD = 3.81). We acknowledge that this limitation reduces the external validity of our findings, particularly for populations with higher BMIs."

Author contributions
IDEA/CONCEPT: K.G. DESIGN: J.M.A., K.G. CONTROL/SUPERVISION: J.M.A., K.G., N.Sh., S.Sh. DATA COLLECTION AND/OR PROCESSING: J.M.A., N.Sh. ANALYSIS AND/OR INTERPRETATION: J.M.A., S.Sh. LITERATURE REVIEW: J.M.A., N.Sh., S.Sh. WRITING THE ARTICLE: J.M.A., N.Sh. CRITICAL REVIEW. K.G., N.Sh. REFERENCES AND FUNDINGS: J.M.A., S.Sh.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by Baskent University İnstitutional Review Board and Ethics Committee (**Proje No: KA24/102**) and supported by Baskent University Research Fund.

Competing interests
The authors declare no competing interests.

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